

April 8, 1952

H. C. OTIS ET AL

2,592,325

WELL FLOW REGULATING APPARATUS

Filed Jan. 28, 1943

3 Sheets-Sheet 1

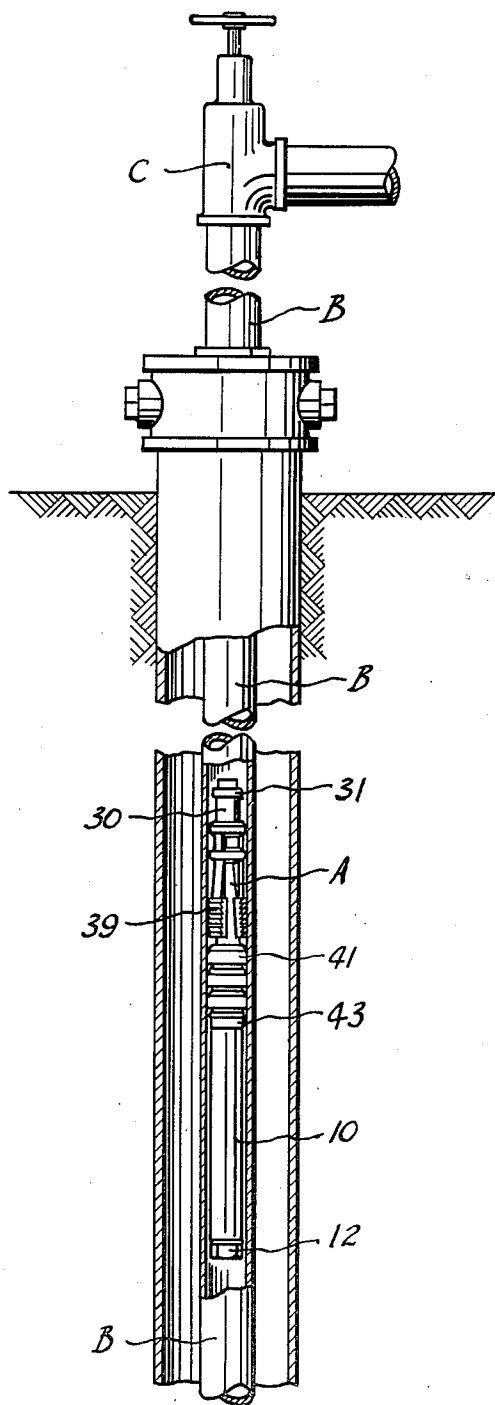


FIG. 1

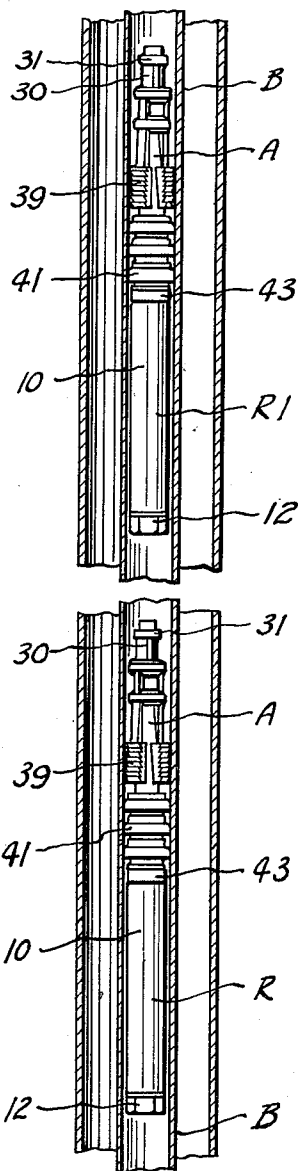


FIG. 12

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3 Sheets-Sheet 2

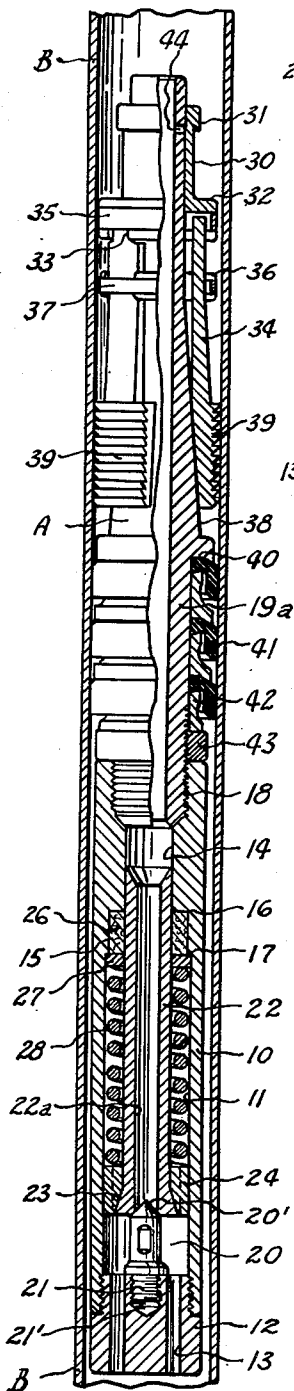


FIG. 2

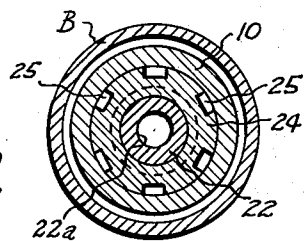


FIG. 4

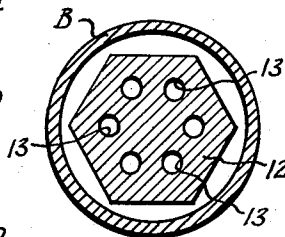


FIG. 5

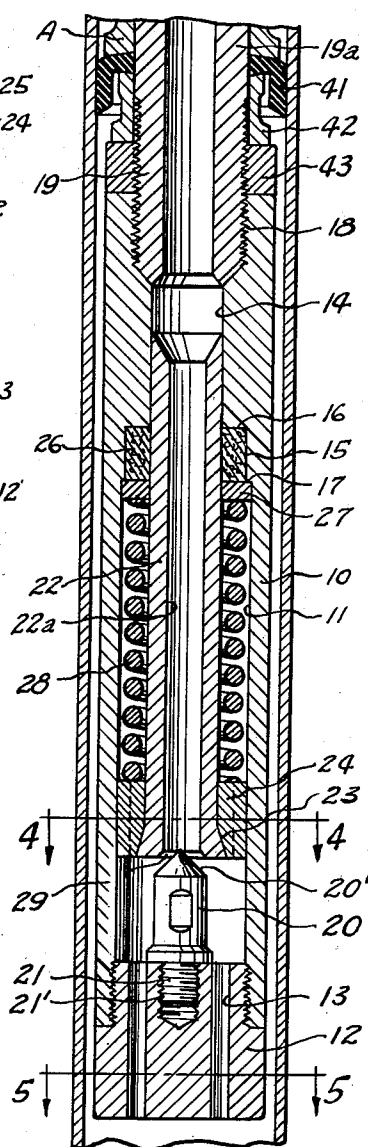


FIG. 3

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3 Sheets-Sheet 3

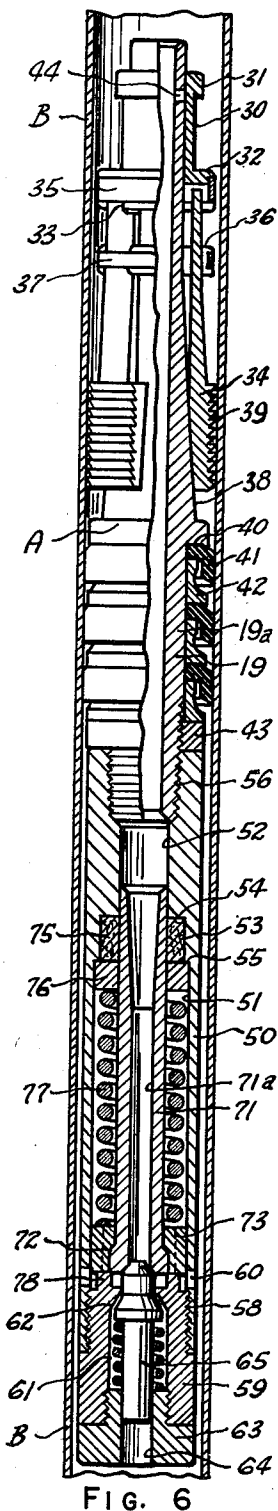


FIG. 6

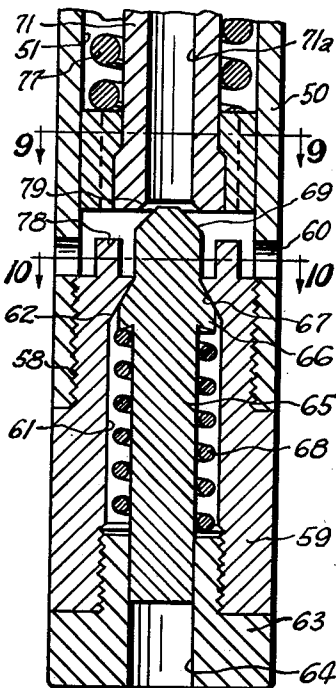


FIG. 7

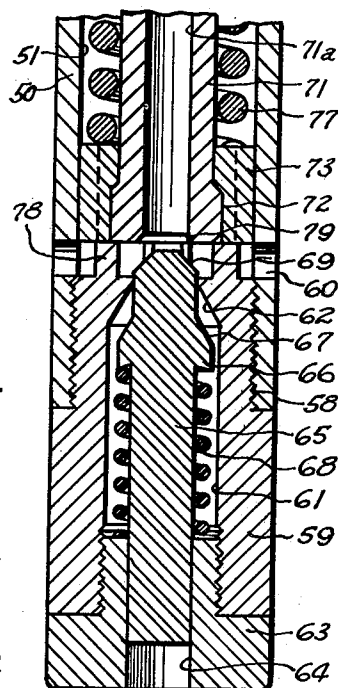


FIG. 8

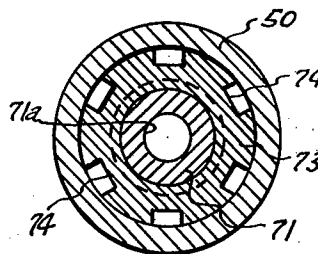


FIG. 9

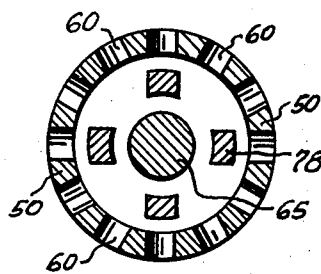


FIG. 10

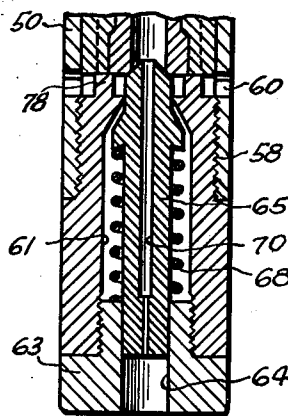


FIG. 11

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2,592,325

WELL FLOW REGULATING APPARATUS

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Application January 28, 1943, Serial No. 473,838

6 Claims. (Cl. 166—2)

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This invention relates to new and useful improvements in well flow regulating apparatuses.

The application is filed as a continuation in part of our co-pending application Serial No. 329,064, filed April 11, 1940, now abandoned, and as a continuation in part of our co-pending application Serial No. 288,004, filed August 2, 1939, now abandoned.

In oil and gas wells wherein the well fluids are delivered to the surface at relatively high pressures, various means have been employed for controlling or regulating the rate of withdrawal of the well fluids from the well. One such means has been the surface choke or regulator, but due to the temperature loss occasioned by the expansion of the gas from the high well pressure to the line pressure, particularly where the gas-to-oil ratio is high or the fluid is substantially all gas, such means is not satisfactory. In using a surface choke or regulator to control the rate of withdrawal of the well fluids from the high pressure well, the temperature loss due to the expansion of the gas from the high well pressure to the line pressure is often so great that freezing occurs at or beyond the surface choke or regulator, with the result that expensive heating equipment is necessary to overcome this freezing. In many instances, bottom hole chokes have been employed to control the rate of withdrawal from the well and, in such cases, the pressure drop from the high well pressure to the approximate line pressure is made at a depth where the higher subsurface temperature precludes freezing at the choke where the expansion takes place. However, the usual bottom hole choke ordinarily consists of a fixed orifice or bean and, therefore, only a predetermined withdrawal of the well fluids is possible.

Attempts have been made to vary the rate of withdrawal from wells by providing a surface choke or regulator in addition to a bottom hole choke having its flow orifice or bean of a fixed capacity. However, due to the phenomenon of critical flow of gases, it generally occurs that when the rate of withdrawal from a high pressure well, which is equipped with a bottom hole choke, is further reduced, or varied, through the use of a surface choke or regulator, the pressure drop across the surface choke becomes so great that freezing occurs at the surface. This is true because, when the flow at the surface is regulated to reduce the pressure down to the line pressure, a back pressure is built up in the tubing above the bottom hole choke and this results in a reduction of the pressure drop across the bottom hole

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choke, with the result that the well fluids are delivered to the surface choke at too great a pressure to obviate freezing. Therefore, it has been found that the use of a surface choke, in addition to the bottom hole choke having a fixed flow orifice, does not permit regulation of the rate of withdrawal of the well fluids without freezing at the surface taking place. Manifestly, if a predetermined or fixed pressure drop could be maintained across the bottom hole choke or regulator, regardless of the rate of withdrawal of the well fluids, then the well fluids would be delivered to the surface choke at a pressure which would permit regulation of the rate of withdrawal without freezing, whereby the expensive heating equipment, now in general use, could be eliminated.

It is, therefore, one object of this invention to provide an improved bottom hole regulator having variable flow control means which is automatically varied in accordance with the rate of withdrawal of the well fluids from the well, whereby the fluids are delivered to the surface at a pressure which permits surface regulation without freezing, thus eliminating the use of expensive heating systems at the surface.

An important object of the invention is to provide an improved bottom hole regulator or variable choke which is actuated by the pressure differential thereacross, whereby a predetermined pressure drop across the choke is automatically maintained under various flow conditions, thereby permitting a flexible rate of withdrawal of well fluids from the well without danger of freezing at or beyond the surface well connections; the device eliminating the necessity for the use of surface heaters or heating units, as is now the general practice.

Another object of the invention is to provide a variable bottom hole choke for reducing the well pressure, which is actuated by the pressure differential thereacross and which may be run into, and removed from, the well under pressure on a wire line, whereby replacement of parts, adjustments and repairs are facilitated.

A further object of the invention is to provide improved regulating apparatus for controlling or regulating the flow from a well, wherein a bottom hole choke having variable flow means, which is actuated by the pressure differential thereacross, may be disposed in the lower portion of the flow conductor to control, within limits, the pressure at which the well fluids are delivered at the surface, together with a manually adjustable surface choke which accurately regulates

the rate of withdrawal of the well fluids; the arrangement permitting accurate regulation of flow without danger of freezing at the surface control.

Still another object of the invention is to provide an improved device, of the character described, wherein a valve element and a valve seat element are movable one with relation to the other to effect a control of the flow and a regulation of the pressure from the producing area of the well, such movement being accomplished by pressures above and below said device; the pressure above being varied by adjusting the surface controls, whereby the actuation of the device is controlled, within certain limits, from the surface.

A particular object of the invention is to provide an improved bottom hole regulator wherein a stationary member is located at the lower portion of the device and a tubular valve element is arranged to move relative to the member to control the flow past said member, the valve element being movable downwardly toward its closed position against the line or direction of flow of the fluid, whereby the effect of the flowing fluid on the element is minimized and a more efficient regulating action produced.

Another object of this invention is to provide an improved bottom hole regulator or choke having variable means for regulating the flow of well fluids upwardly therethrough in accordance with the rate of withdrawal of said fluids from the well and being so constructed that a reverse or downward flow of fluids therethrough may be effected.

Under ordinary flowing conditions when the well fluids are flowing upwardly toward the surface, a stationary valve seat and a movable valve co-acting therewith will function efficiently to control and regulate the flow. However, occasions arise where it is desirable or necessary to pump fluid downwardly through the tubing from the surface, through the regulator, and into the formation; for example, when it is desired to "kill" the well, that is, stop the normal flow thereof. In order to accomplish this, it is desirable to arrange a movable seat member in the regulator which may be opened to permit fluid to be pumped down to the formation when the valve is normally closed.

A particular object of the invention is to provide an improved regulating apparatus, of the character described, wherein the valve element, which co-acts with a movable member to effect a control of the flow, is yieldably held in position, whereby normally it may function with the member to control or regulate upward flow through the apparatus; said valve being movable from its normal position so as to permit a reverse flow through said apparatus.

Still another object of the invention is to provide an improved regulating apparatus having a pair of spring-loaded valve elements, one of said elements being stationary while the other is movable during upward flow of fluids through the apparatus, whereby a control of the upward flow is effected; the element which is stationary during upward flow through the apparatus being movable, and the other element being stationary, upon a reversal of flow through the apparatus, whereby fluid may be circulated downwardly through said apparatus.

A construction designed to carry out the invention will be hereinafter described, together with other features of the invention.

The invention will be more readily understood from a reading of the following specification and by reference to the accompanying drawings, in which an example of the invention is shown, and wherein:

Figure 1 is a view, partly in section and partly in elevation, of an improved bottom hole regulator, constructed in accordance with the invention and illustrating the same mounted within a well tubing,

Figure 2 is an enlarged view, partly in section and partly in elevation, of the regulator locked within the well tubing and in its closed position to prevent flow through said tubing,

Figure 3 is an enlarged transverse, vertical, sectional view, showing the regulator in its open position to permit a flow therethrough,

Figure 4 is a horizontal, cross-sectional view, taken on the line 4—4 of Figure 3,

Figure 5 is a horizontal, cross-sectional view, taken on the line 5—5 of Figure 3,

Figure 6 is a view, partly in section and partly in elevation, of a regulating apparatus, constructed in accordance with the invention, and illustrating another form,

Figure 7 is an enlarged, transverse, vertical, sectional view of the lower portion of the apparatus and showing the parts in a position controlling upward flow through said apparatus,

Figure 8 is a similar view, with the parts in a position permitting a downward circulation through the apparatus,

Figure 9 is a horizontal, cross-sectional view, taken on the line 9—9 of Figure 7,

Figure 10 is a horizontal, cross-sectional view, taken on the line 10—10 of Figure 7, and

Figure 11 is an enlarged sectional view of the lower valve element and showing an axial passage extending therethrough.

Figure 12 is a view partly in section and partly in elevation showing a plurality of regulators mounted in a well.

In the drawings, the numeral 10 designates an elongate cylindrical body having a bore 11 extending therethrough. The lower end of the bore is provided with internal screw threads whereby a plug 12 may be threaded therinto and said plug is formed with a plurality of vertical passages or openings 13, whereby a flow into the interior of the body 10 may occur. The upper end of the bore 11 is reduced, as indicated at 14, and immediately below the reduced portion an offset 15 is provided, whereby an internal annular shoulder 16 is formed within said body. Below the offset portion 15, a second smaller shoulder 17 is provided. The upper end of the body is counter-bored at 18, whereby the lower end of a tubular mandrel 19 of a suitable running tool A may be connected with said body. The running tool A will be hereinafter described and may be of any suitable construction, said tool providing a means whereby the body 10 may be readily lowered into and removed from a well tubing B.

A stationary valve element or pin 20 is mounted within the body 10, being secured to the plug or closure 12, which closes the lower end of said body. As is clearly shown in Figures 2 and 3, the valve element is formed with a depending threaded pin 21 which is screwed into an axial opening 21' formed in the top of the plug 12. The upper portion of the pin is formed with a conical portion 20' and said pin extends upwardly and axially within the bore. Fluid which may enter the vertical passages 13 in the plug 12 will

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pass into the bore 11 of the body 10 and flow upwardly past the valve element 20.

An elongate tubular seat element or valve sleeve 22 is slidably mounted within the bore of the body 10 and has its upper portion slidably engaging the reduced portion 14 of the bore so as to be guided in its vertical movement. The lower end of the sleeve 22 is flared outwardly, as shown at 23, and a guide collar 24 surrounds this lower end. The lower portion of the bore of the guide collar is flared outwardly so as to be complementary to the flared outer surface of the sleeve and said collar has a tight fit on the sleeve. As is clearly shown in Figure 4, the guide collar 24 is formed with a plurality of vertical recesses or notches 25 which are located in its peripheral portion and said openings permit a free flow of fluid past said collar. The periphery of the collar has a diameter substantially equal to the bore 11 of the body 10 so as to have a sliding fit therein.

A plurality of packing rings 26, which are preferably of the chevron type, surround the upper portion of the tubular sleeve 22, the uppermost packing ring abutting the shoulder 16. The lowermost packing ring rests on a ring 27 which has its outer peripheral edge abutting the shoulder 17 and, manifestly, the space between the ring 27 and the shoulder 16 forms a packing chamber which receives said rings. A coiled spring 28 surrounds the tubular sleeve 22 and has its upper end engaging the underside of the ring 27, while its lower end engages the top of the guide collar 24. The spring exerts its pressure to constantly urge the valve sleeve 22 downwardly toward the valve pin or element 20.

The lower end of the bore 22a of the sleeve 22 is formed with an annular valve seat 29 and, when the sleeve 22 is in its lowermost position, said seat is engaging the conical surface 20' of the valve member, as is clearly shown in Figure 2. In this position, any flow upwardly through the passages 13 of the plug 12 from below the assembly is prevented from flowing upwardly through the bore of the sleeve 22 and then through the tubular mandrel 19 of the running tool A. However, when the valve sleeve 22 is lifted off of the pin 20, a flow may occur through the sleeve 22 and upwardly into the tubing above the running tool A.

As explained, any suitable tool may be connected with the upper portion of the body 10, whereby the device may be lowered and raised within the well tubing or conductor B. However, it is preferable to employ the tool A, which is disclosed in the drawing and which is similar to the running tool shown in the H. C. Otis Patent No. 1,972,791, issued September 14, 1934. This tool includes the tubular mandrel 19 which has the upper portion of its outer surface substantially cylindrical, whereby a slip supporting sleeve 30 may be slidably mounted thereon. The sleeve is formed with an outwardly directed, annular flange 31 at its upper end and an external collar 32 is preferably made integral with its lower end. The collar has a plurality of radial slots 33 therein, which slots are spaced equidistant therearound and the upper ends of gripping elements 34 are inserted within the slots. A retaining ring 35 which surrounds the collar prevents outward displacement of the elements from said slots. Manifestly, the gripping elements are suspended from the sleeve 30 and are movable with relation to the mandrel. For limiting the movement of the sleeve on the mandrel, the latter is formed with an external flange 36, preferably integral

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therewith. This flange is slotted to permit the gripping elements 34 to extend therethrough and a confining ring 37 surrounds the flange and confines the elements within the slots thereof, whereby said gripping elements are retained in close proximity to the outer surface of the mandrel.

Immediately below the flange 36, the surface of the mandrel is flared or inclined outwardly to form a slip-expanding portion 38. Each gripping element 34 includes an arcuate slip 39 at its lower end and the inner surfaces of the slips engage and ride upon the inclined surface 38 of the mandrel. The outer surface of each slip is provided with gripping teeth which are adapted to engage the inner wall of the well tubing B to prevent upward displacement or movement of the slip and mandrel. When the slips 39 are at the upper end of the inclined portion 38 and immediately below the flange 36, they are retracted and out of engagement with the wall of the tubing B; however, movement of the slips downwardly with relation to the mandrel 19 causes the outward radial movement thereof to the position shown in Figure 2, whereby said slips engage the tubing wall to hold the mandrel in position.

Below the slip-expanding or inclined surface 38, the mandrel is formed with a reduced shank 19a, whereby an external annular shoulder 40 is provided. A plurality of elastic packing cups 41 surround the shank, being spaced from each other by suitable spacing collars or rings 42. The uppermost cup abuts the shoulder 40 and the cups and spacers are retained on the shank by a retaining collar 43 which is threaded onto the lower end of said shank. The extreme lower end of the shank threads into the counter-bore 18 of the body 10, as is clearly shown in Figure 3. Normally, there is a clearance between the cups and the wall of the tubing B, but when the device is set within said tubing, as will be explained, the well fluid pressure below the device acts upwardly against the packing cups 41 to deform the same into sealing engagement with the wall of the well tubing, whereby the annular space between said tubing and the mandrel is sealed off.

In lowering the assembly into the well tubing B, a suitable lowering device (not shown) is connected to the upper end of the mandrel 19 by means of sheer pins (not shown) or other releasable means, which extend through openings 44 provided for this purpose. The assembly is thus suspended from the lowering device which is attached to a cable or wire line, and the lowering is contained until the depth at which it is desired to set the assembly is reached. During the lowering operation, the slips 39 merely ride on the surface of the tubing wall but do not take hold as the mandrel is constantly moving ahead of said slips. Before lowering the assembly, the well control devices which may include a surface choke C, at the surface of the well tubing B have been closed to shut off any flow through the tubing and, therefore, the assembly moves downwardly through the fluid which might be standing in the well, the pressures across said device or assembly being equalized. The packing cups 41 are in a normal undistorted position whereby there is a clearance between said cups and the tubing wall to permit by-passing of the well fluid within the tubing around the assembly as it is lowered there-through. In order to set the assembly within the tubing B, an upward pull is exerted on the

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mandrel 19 by means of the lowering device (not shown). Such upward movement of the mandrel causes the free riding slips 39 to be moved outwardly by the inclined surface 38, whereby the slip teeth engage the tubing wall. Repeated upward jarring tends to more firmly set the slips and such upward jarring also shears the pins (not shown) which extend through the openings 44 in the mandrel, after which the lowering device is removed from the tubing. It is pointed out that the device could be set in other ways, as for example, by connecting the lowering means to the slip collar 30 and jarring downwardly.

Since the pressure is equalized across the assembly during the lowering thereof, it will be manifest that the coiled spring 28 urges and holds the valve sleeve 22 in its lowermost position, as shown in Figure 2, whereby the seat 29 at the lower end of said sleeve is engaged with the valve pin 20 to prevent a flow through the assembly. After the slips 39 have been set, the surface choke C is opened to permit the well fluid to flow upwardly through the tubing. As soon as this flow starts, the packing cups 41 are deformed by the well fluid pressure into sealing engagement with the well tubing. The fluid pressure may also act against the assembly to urge the mandrel 19 upwardly and thereby further tighten the gripping engagement of the slips 39 with the tubing B.

The pressure within the tubing B above the assembly is, of course, acting downwardly on the upper end of the tubular valve sleeve 22. This downwardly acting pressure is urging the sleeve to its lowermost position and is aided by the compression of the spring 28. The lower end of the sleeve 22 is exposed to the pressure of the well fluid below the assembly, which pressure is substantially the bottom hole pressure of the well. When the device is first set within the well and the pressures across the assembly are equalized, the spring 28 serves to hold the valve sleeve 22 lowered, whereby the bore of said sleeve is closed by the valve pin. When the surface controls are opened to permit a flow from the upper end of the tubing B, this flow will result in a reduction of the pressure in the tubing above the assembly and since this pressure is acting upon the upper effective cross-sectional area of the sleeve 22, it will be manifest that the pressure, which is resisting the bottom hole well pressure, is lowered. As soon as this pressure is lowered to a point where the bottom hole pressure acting against the underside of the sleeve 22 is sufficient to overcome the same, plus the compression of the spring 28, the sleeve 22 is moved upwardly, whereby the valve seat 29 is disengaged from the valve pin 20. As soon as this occurs, the well fluid entering the bore 11 of the body through the passages 13 in the plug 12, flows upwardly through the bore 22a of the sleeve and then through the tubular mandrel 19 and into the tubing above the assembly. A reversal of pressures will cause the valve to seat; however, the prime object of the invention is to regulate upward flow while the valve is open.

In this form of the invention the effective cross-sectional area of the sleeve 22, which is exposed to the fluid pressure in the tubing above said sleeve, is substantially the same as the effective cross-sectional area which is exposed to the bottom hole fluid pressure below said sleeve. Thus the spring 28 plays an important part in closing the valve, or as will be hereinafter explained, in urging the valve sleeve 22 toward its

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closure pin 20 to regulate the flow through the valve. The spring may be compressed to exert a predetermined expansive force and thus hold the valve sleeve closed until its expansive force is overcome.

For example, if the spring 28 was compressed so that its expansive force acting downwardly through the medium of the valve sleeve 22, was equal to a downward pressure of 1200 lbs. per sq. in., acting downwardly on the sleeve, and if there was a fluid pressure of 800 lbs. per sq. in., in the tubing and regulator above said valve acting downwardly thereon, then a bottom hole pressure slightly more than 2000 lbs. per sq. in., acting upwardly against the valve, would be required to open it.

From the foregoing, it will be seen that while the expansive force imposed upon the sleeve 22 by the spring 28 determines the pressure differential under which the valve opens, and operates while open, it does not determine the pressure from below which is necessary to open the valve. However, this expansive force co-acting with the downward fluid pressure exerted on the sleeve controls the operation of said sleeve valve. It is of course necessary to maintain a pressure differential to hold the valve open, and because of the spring the sleeve is under automatic regulation while the well fluid is flowing upwardly there-through, thus maintaining a fixed pressure drop across said sleeve.

It is obvious that the compression of the spring 28 determines the pressure differential, across the valve, at which the regulator operates. The compression of the spring 28 may be varied by changing the thickness of the ring 27, and rings of different thickness may be provided for this purpose.

It will be observed that as the sleeve 22 moves upward to open the valve, the spring 28 will offer increasing resistance and will be further compressed. The flow through the valve will be controlled by the co-acting faces of the valve seat 29 and the conical portion 20' of the pin 20. Thus, the valve sleeve will automatically adjust itself to varying rates of flow upwardly through the tubing B. However, in co-action with the surface control C, the regulator will maintain substantially a fixed differential or pressure drop thereacross, under normal flowing conditions, regardless of the rate of flow.

The maintenance of a substantially fixed pressure drop across the assembly assures that the well fluids are delivered to the surface at a predetermined pressure, which is sufficiently low to permit surface regulation, by means of the surface choke C, without danger of freezing. To further explain, assuming the well fluids are delivered to the surface at 1000 pounds pressure at a predetermined rate of flow, then if the surface choke C is regulated to reduce the rate of flow, a change in pressure conditions in the tubing above the regulator assembly occurs, and the sleeve 22 automatically adjusts itself to restrict the flow therethrough so as to maintain the predetermined pressure drop thereacross, with the result that the well fluids are continuously delivered to the surface at a predetermined reduced pressure. Thus, regardless of the rate of withdrawal of the well fluids under normal flowing conditions, the pressure at which the fluids are delivered to the surface is maintained sufficiently low to obviate freezing.

Since the assembly is set within the lower end of the well, advantage is taken of the relatively

high subsurface temperatures, whereby freezing at the assembly due to the expanding gas is precluded. The device may be quickly lowered into the well tubing and set at any desired point therein, being capable of being run in under pressure on the flexible line or cable.

The removal of the entire assembly may be accomplished at any time by merely lowering a suitable removing device (not shown) and engaging the same beneath the shoulder 31 on the slip-carrying sleeve 30. The lowering tool may include a jar so that the mandrel may be jarred downwardly with relation to the slips to release the latter. The wire line and tool are then raised, whereby the sleeve 30 and the gripping elements 34 are raised with relation to the mandrel. The slips move upwardly on the inclined portion 38 until they abut the extending shoulder 36 on the mandrel. In this position, the slips are retracted and a continued upward movement will result in the removal of the assembly from the well tubing. From the foregoing, it will be seen that the device may be readily run into and removed from the well tubing by means of a wire line or cable.

It has been found that under some conditions it is necessary to drop the pressure across the regulator in excess of 1500 pounds per square inch. When these high pressure drops are necessary, it is not particularly practical to effect this relatively high drop across a single regulator because the velocity of the flow is increased to the extent that damage to the assembly may result due to cutting action of abrasives present in the flowing fluid. In these instances, it is desirable that more than one regulator be employed. In such case, as is clearly shown in Figure 12, one regulator R is set near the lower end or bottom of the well and a second regulator R1 is mounted within the tubing at a distance spaced from the first regulator. The lowermost regulator R may be set to drop the pressure across its assembly so that such drop is between 750 and 1000 pounds. The second R1 may then additionally drop the pressure another 750 to 1000 pounds, and, in this manner, the well fluids are delivered at the surface at the required pressure without placing undue strain or wear on the regulating devices. It is noted that the predetermined pressure drop, for which each regulator is adjusted, is maintained thereacross, regardless of the rate of withdrawal of the well fluids. Thus, each regulator carries its portion of the load which is evenly distributed therebetween. Due to the critical flow of gases, a constant pressure drop cannot be maintained across each of a series of bottom hole chokes, which have fixed flow orifices, because a change in the rate of withdrawal of the well fluids results in a change in such pressure drop, with the result that one of said chokes must carry the greater portion of the load. The variable regulator, illustrated herein, makes it possible to employ a series of regulators with each maintaining its predetermined pressure drop under all flow conditions.

It is within the scope of the invention to have either or both of the valve members movable. In Figures 6 to 11 inclusive we have illustrated another form of the invention. In this form an elongate cylindrical body 50 is provided with a bore 51 extending therethrough.

The upper end of the bore 51 is reduced, as indicated at 52, and immediately below the reduced portion an offset 53 is provided, whereby an internal, annular shoulder 54 is formed within the

bore of the body. Below the offset portion 53, a second and smaller shoulder 55 is provided. The upper end of the body is counter-bored at 56 and the counterbore has internal screw threads, whereby the lower end of a tubular mandrel 19 of the running tool A may be connected with the body.

The lower end of the bore 51 is provided with internal screw threads 58, and a thimble or collar 59 is threaded into the bore. Immediately above the threaded portion of the bore, the body 50 has a plurality of radial openings 60 extending therethrough, whereby communication is established between the bore of the body 50 and the interior of the well tubing B.

A bore 61 extends axially through the thimble 59 and has its upper end bevelled inwardly to form an annular shoulder or stop 62. The lower end of the bore 61 is provided with screw threads which receive a plug 63. The plug has an axial opening 64 extending therethrough and, as is clearly shown in Figures 7 and 8, this opening is of a smaller diameter than the diameter of the bore 61. A valve element or plunger 65 is slidably mounted within the bore 61 and within the opening 64 of the plug 63, the lower end of said element being of substantially the same diameter as the opening 64, whereby the element is guided in its vertical movement. The upper portion of the valve element 65 is formed with an integral flange 66 and the upper surface of said flange is bevelled or inclined, as shown at 67. This incline or bevel is complementary to the inclination of the shoulder 62 whereby when the valve element is in its raised position, as shown in Figure 7, said bevelled surface engages the shoulder to limit the upward movement of the valve element. A compression spring 68 surrounds the valve element 65 and is confined within the bore 61, the upper end of said spring engaging beneath the flange 66 on said valve element. The lower end of the spring rests on the upper end of the plug 63 and, manifestly, the spring exerts its force to constantly urge the valve element to its uppermost position.

When the valve element is in its uppermost position, as shown in Figure 7, its upper end projects from the upper end of the bore 61 and above the lateral ports or openings 60 in the wall of the body 50. The extreme upper end of the valve element is bevelled to provide an annular seating surface 69.

An elongate, tubular valve sleeve 71 is slidably mounted within the bore of the body 50 and has its upper portion slidable in the reduced portion 52 of the bore so as to be guided in its vertical movement. The lower end of the sleeve 71 is formed with an annular boss 72, and a guide ring 73 surrounds this boss. The upper portion of the bore of the guide ring is reduced in diameter so as to engage over the boss 72 of the sleeve and said ring has a tight fit on said boss. The guide ring 73 has a plurality of vertical grooves or recesses, 74 formed in its outer periphery and said openings permit a free flow of fluid past the same. The periphery of the ring has a diameter substantially equal to the bore 51 of the body 50, whereby it has a sliding fit therein.

A plurality of packing rings 75, which are preferably of the Chevron type, surround the upper portion of the tubular sleeve 71, the uppermost packing ring abutting the shoulder 54. The lowermost packing ring rests on a follower ring 76 which has its outer peripheral edge abutting the shoulder 55 and manifestly, the space between the

ring 76 and the shoulder 54 forms a packing chamber which receives the packing rings 75. A coiled spring 77 surrounds the tubular sleeve 71 and has its upper end engaging the underside of the ring 76, while its lower end engages the top of the guide collar 73. The spring being under compression tends to expand and exerts its force to constantly urge the valve sleeve 71 downwardly towards the valve element 65. Downward movement of the tubular valve sleeve 71 within the bore 51 is limited by a plurality of upstanding stop lugs or projections 78, which extend upwardly from the upper end of the collar 59 which houses the valve element 65. As shown, these lugs have their upper surfaces terminating in substantially the same plane as the top of the lateral ports or openings 60 in the wall of the body 50, but below the bevelled seating surface 69 of the valve element 65, whereby when said element is in its normal position engaging the shoulder, the sleeve 71 engages the seating surface 69 of the valve element and is held above the stop lugs. Thus the sleeve will always engage said seat to shut off flow therethrough before engaging the lugs. The provision of the stop lugs 78 makes it impossible for the valve sleeve 71 to move downwardly into engagement with the top of the collar 59, which is below the lateral ports or openings 60.

The lower end of the bore 71a of the sleeve 71 is provided with an annular valve seat 79 and when the parts are in the position shown in Figure 6, said seat is engaging the bevelled surface 69 on the valve element 65, whereby any flow through the valve sleeve 71 is prevented. When the parts are in the position shown in Figure 7, with the valve sleeve lifted off of the valve member 65, an upward flow of fluid may occur through the ports 60 and then upwardly through the bore 71a of the sleeve 71. When the parts are in the position shown in Figure 8, with the sleeve resting on the stop lugs 78, the valve element 65 may be moved downwardly within the bore 61 to permit a flow downwardly through the bore 71a of the sleeve 71 and then outwardly through the ports 60.

The body 50 also has a screw threaded counter-bore 56 in its upper end to receive the reduced shank 19a of the running tool A, as hereinbefore explained. The regulator is positioned in the same manner as the form shown in Figures 1 to 5 inclusive.

Since the pressure is equalized across the assembly during the lowering thereof, it will be manifest that the coiled spring 77 urges and holds the valve sleeve 71 in its lowermost position in engagement with the upper ends of the stop lugs 78, as shown in Figure 6. In such position, the valve seat 79 at the lower end of the sleeve is engaged with the bevelled surface 69 of the valve element to prevent a flow through the assembly. After the slips 39 have been set, the surface connections are opened to permit a flow of the well fluid upwardly through the tubing. As soon as this flow starts, the packing cups 41 are deformed by the well fluid pressure into sealing engagement with the well tubing. The fluid pressure may also act against the assembly to urge the mandrel 19 upwardly and thereby further tighten the gripping engagement of the slips 39 with the tubing B.

The pressure within the tubing B above the assembly is acting downwardly on the upper end of the tubular valve sleeve 71 and this pressure is urging the sleeve to its lowermost position,

being aided by the force of the spring 77. The lower end of the sleeve 71 is exposed to the pressure of the well fluid below the assembly through the ports 60 in the wall of the body 50 and this pressure is the pressure within the well at the elevation at which the device is set. When the device is first set within the well and the pressure across the assembly is equalized, the spring 77 holds the valve sleeve lowered, whereby the bore of said sleeve is closed by the valve element 65. In such position, the sleeve may have moved the valve element downwardly a slight distance within the bore 61 of the thimble 59 since the spring 77 is of greater strength than the spring 68 which acts to urge the valve element upwardly. When the surface controls are opened to permit a flow from the upper end of the tubing B, this flow will result in a reduction of the pressure in the tubing above the assembly which is acting upon the upper effective cross-sectional area of the sleeve 71. As soon as this pressure above the assembly is lowered to a point where the pressure acting against the underside of the sleeve 71 is sufficient to overcome the pressure thereabove, plus the force of the spring 77, the sleeve 71 is moved upwardly, whereby the valve seat 79 is disengaged from the valve element 65. Of course, upon initial movement of the sleeve 71 in an upward direction, the valve element moves upwardly until the bevelled shoulder 67 engages the shoulder or stop 62 within the bore 61 and when this occurs, further upward movement of the element is prevented.

As soon as the sleeve 71 moves away from the upper end of the valve element 65, the well fluid entering through the lateral ports 60 flows upwardly through the bore 71a of the sleeve 71 and then through the tubular mandrel 17 and into the tubing above the assembly. A reversal of pressures will cause the valve to seat, however the function of the device is to regulate the upward flow when the valve is open, as hereinbefore pointed out.

It is noted that the effective cross-sectional area of the sleeve 71 which is exposed to the pressure in the tubing above the assembly is substantially the same as the effective area which is exposed to the pressure below the assembly. Therefore, it will be obvious that the differential at which the valve sleeve 71 will be moved upwardly off of the valve element is substantially controlled by the compression of the coiled spring 77. Thus, by adjusting the compression of this spring, a predetermined pressure differential will be required to unseat the valve seat 79 and permit a flow through the device. By varying the compression of the spring 77, it is possible to accurately control the differential necessary to operate or move the sleeve 71 and thus control the pressure drop across the assembly. It is pointed out that the adjustment of the spring 77 may be readily accomplished by merely changing the thickness of the ring 76 which is mounted within the bore of the body 50. Under varying flow and pressure conditions, it will be seen that the sleeve 71 will automatically adjust itself relative to the valve element 65 to vary the rate of flow upwardly through the tubing B and to the surface, but, at all times, a fixed differential or pressure drop is maintained across the assembly, which drop is maintained regardless of the rate or volume of flow. The maintenance of a fixed pressure drop across the assembly assures that the well

fluids are delivered to the surface at a predetermined reduced pressure, which is sufficiently low to permit surface regulation without danger of freezing.

During the time that the valve sleeve 71 is actuated by the pressure differential thereacross to control the flow upwardly from the formation and through the tubing, the valve element 65 is in the position shown in Figure 7. The pressure below the valve element is urging the same upwardly at all times and this pressure is greater than the pressure which is acting downwardly against the valve element, because the downwardly acting pressure is the reduced flowing pressure within the tubing above the device. Thus, while the sleeve 71 is regulating upward flow, the pressures across the valve element are unbalanced with the greater pressure being exerted against the lower end of said element to maintain the same in a raised position in engagement with the shoulder or stop 62. The force of the coiled spring 68 is, of course, added to the pressure below the element. Therefore, while the sleeve 71 is functioning to regulate the flow, the valve element is, in effect, stationary and does not in any way undergo a movement to aid in the control of the upward flow.

On many occasions, it may become desirable to pump fluid downwardly through the tubing and through the assembly back into the producing formation. In such case, it is only necessary to close the surface controls at the upper end of the tubing, whereby all flow through the tubing is stopped. When this is done, the pressure above the sleeve will build up until such pressure plus the effective pressure of the spring will move the sleeve downwardly against the pressure therebelow to the position shown in Figure 6. A fluid may then be pumped downwardly through the tubing from the surface and will flow downwardly through the tubular mandrel 17 and then through the sleeve 71. The additional pressure of the pumped fluid will act against the upper end of the valve element 65 and will serve to force said element downwardly against compression of the spring 68 to the position shown in Figure 8. It is noted that the spring 68 is relatively light so that it may be readily compressed without the necessity of employing excessive pressures. When the element moves downwardly, the sleeve engages the stop lugs 78 and the fluid may pass outwardly through the lateral ports or openings 60 in the wall of the body 50 and into the formation. Whenever the additional pressure of the fluid being pumped downwardly through the well tubing decreases to a point less than the compression of the spring 68, said spring immediately moves the valve element upwardly into engagement with the lower end of the valve sleeve 71 to again close the bore of said sleeve. Thus, it will be seen that the provision of the valve element 65, together with its yieldable mounting, makes it possible to pump a fluid downwardly through the assembly in a reverse direction.

In Figure 11, a slightly modified form of the valve element 65 is shown wherein said element is provided with a relatively small axial passage 70 which extends vertically therethrough. The passage is not sufficiently large to interfere with the normal working or operation of the parts, as above described, and is provided as a pressure equalizing passage and also as a means for taking care of certain conditions which might arise.

When the well is shut in, due to closure of the surface connections, it will be manifest that the passage 70 permits an equalization of pressures across the device. Such equalization of the pressures across the device is desirable in order to facilitate removal of the assembly from the well. The passage 70 also functions to prevent overloading of the tubing above the assembly. In some instances, a liquid load may be built up in the tubing above the assembly, whereby the parts are moved to a shut off position, as shown in Figure 6, and a flow through the ports 60 and sleeve 71 from below the assembly cannot occur until such load is removed. Under such conditions, the passage 70 allows the pressure below the assembly, which is the full well pressure, to pass upwardly into the tubing thereabove and this pressure acts to lift the liquid and unload the tubing. As soon as the liquid load is relieved to predetermined point, the necessary differential is set up across the valve sleeve 71 and said sleeve is actuated as has been explained. It is pointed out that the passage 70 is not essential to the operation of the device but is desirable under certain conditions and the provision of such passage is optional.

The qualification "rate of flow" as used herein is intended to cover the volume and/or velocity of flow. While one object of the invention is to eliminate freezing, where freezing is likely to occur, there may be wells where the bottom hole temperatures are so high that the well stream may be produced at the well head without freezing. However, the amount of pressure reduction at the well head, through the surface controls, which can be accomplished without freezing where the bottom hole temperatures are high, will depend upon the composition of the well stream and the use of the invention may vary accordingly. In any well flow stream the automatic regulation is of extreme advantage.

It is obvious that the arrangement whereby the regulator may be run into the tubing adjusted therein and removed on a wire line, is of great advantage as it does not require lowering the tubing into the well or removing the tubing therefrom. However it would be possible to have the body 10 or 50, connected directly in the well tubing, although it would not be nearly so desirable.

It is pointed out that there is a definite coaction between the regulator and the surface control. As has been hereinbefore stated, an adjustment of a surface control has no manipulative effect upon a fixed choke or flow bean down in the well tubing. However, when the surface control is adjusted and the regulator herein set forth is mounted in the tubing, there will be an automatic adjustment in the regulator due to the surface control adjustment. The regulator effectively responds to a flow-regulation adjustment of the surface control, as well as fluid flow variations through the regulator.

As hereinbefore pointed out, the main purpose of the regulator is to maintain a fixed pressure drop across the upper movable valve member and this involves regulation of the valve while it is open and fluid is flowing. While a predetermined pressure differential is necessary to open the valve, such a differential is also necessary to obtain automatic regulation while the valve is open. It is also pointed out that by making the spring relatively long, limited movements of the valve sleeve, which occur during the automatic operation, will cause little, if any, variations in the ex-

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pansive force exerted by the spring. This is true because such movements are relatively slight.

The foregoing description of the invention is explanatory thereof and various changes in the size, shape and materials, as well as in the details of the illustrated construction, may be made, within the scope of the appended claims, without departing from the spirit of the invention.

What we claim and desire to secure by Letters Patent is:

1. In a fluid pressure regulator for the fluids of a flowing well having tubing therein, the combination with a surface control for regulating the rate of withdrawal of well fluids from the tubing, of a body provided with means for mounting it in a well tubing upstream of the surface control and having a flow passage therethrough, valve members in the body for controlling the flow of well fluid through the passage of said body at a predetermined substantially constant pressure reduction, one of said valve members being movable toward and from the other valve member, and means constantly urging said movable valve member toward the other valve member to automatically regulate the flow past the valve members in response to adjustments of the surface control to create and to maintain said predetermined, substantially constant reduction in the pressure of the fluid flowing past said valve members, said other valve member being movable and held normally stationary by means yieldably restraining its movement, said other valve member being movable by a downward fluid pressure of fluid in the well tubing to permit a reverse flow of fluid through the regulator.

2. A pressure regulator including, a tubular body having means for anchoring it in a well and having an axial bore with a port in the body establishing communication between said bore and the exterior of the body, a spring loaded valve member mounted within the body normally urged to and held in a predetermined position, a valve sleeve slidably mounted in the bore of the body above the valve member and movable with relation to said member, the sleeve having its upper end exposed to the fluid pressure thereabove and its lower end exposed to the fluid pressure therebelow, resilient means urging said sleeve toward the valve member, and stop means limiting the movement of the sleeve toward the valve member, the yieldable mounting of the valve member permitting movement of said member away from the sleeve by a pressure from above to allow fluid to flow downwardly through the bore of the body and outwardly through the port.

3. A pressure regulator including, a tubular body adapted to be anchored in a well tubing and having an axial bore with a lateral port in the body establishing communication between said bore and the exterior of the body, a spring loaded valve member movably mounted in the body adjacent the lateral port and normally urged to and held in a predetermined stationary position, a valve sleeve slidably mounted in the bore of the body above the valve member and movable with relation to said member, means for limiting downward movement of the valve sleeve so that the lower end of said sleeve is constantly exposed to the upstream fluid pressure, the upper end of the sleeve being exposed to the down-stream fluid

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pressure within the tubing above the said sleeve, and means constantly urging said sleeve toward the valve member to regulate flow of fluid through the bore of the body to create and maintain a substantially constant pressure reduction in the fluid flowing through the body, the yieldable mounting of the valve member permitting downward movement of said member by fluid pressure from above to allow a downward flow of fluid through the body.

4. A well fluid regulator including, a body having a well fluid inlet and a flow passage upwardly therethrough from the inlet, means for securing the body in a well tubing, a first valve member movable in the body, means holding said member normally stationary in said body, a second valve member in the body movable toward and from the normally stationary first valve member, and yieldable means urging the second valve member toward the first valve member set to resist movement of the second valve member from the first valve member to create a predetermined pressure differential across the second valve member and to automatically adjust said second valve member to regulate upward flow between the valve members to maintain said pressure differential substantially constant during variations in flow.

5. A well fluid flow regulator as set forth in claim 4, with means for arresting movement of the second valve member toward the first valve member to permit independent movement of the first valve member away from the second valve member.

6. A well fluid flow regulator including, a body having a fluid flow passage therethrough and provided with means for mounting it in a well tubing, spring pressed valve members movable with relation to each other, one of said valve members being held normally stationary, the other valve member having its opposite ends constantly exposed to fluid pressures above and below it and set to respond to the difference in fluid pressures above and below it to move toward and from the normally stationary valve member to regulate flow through the body to create and maintain a substantially constant reduction in the pressure of fluid flowing through said body.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
31,567	Spooner	Feb. 26, 1861
391,431	Shoff	Oct. 23, 1888
1,199,152	Bruce	Sept. 26, 1916
1,293,178	Osborne	Feb. 4, 1919
1,637,085	Nichols	July 27, 1927
1,876,246	King	Sept. 6, 1932
1,905,592	Knowlton et al.	Apr. 25, 1933
1,913,489	Knowlton et al.	June 13, 1933
1,920,103	Otis	July 25, 1933
1,970,131	Douglas	Aug. 14, 1934
1,972,791	Otis	Sept. 4, 1934
2,006,909	Boynton	July 2, 1935
2,156,429	Garrett	May 2, 1939
2,196,535	Otis	Apr. 9, 1940
2,316,383	Abercrombie	Apr. 13, 1943